3D Frequency Selective Structures Using Multilayer PCBs

Bo Li and Yiming Tang
School of Electronic Science and Engineering
Nanjing University of Posts and Telecommunications
Nanjing, China 210003

Zhongxiang Shen*
School of Electrical and Electronic Engineering
Nanyang Technological University
Singapore 639798
Email: ezxshen@ntu.ed.sg

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Abstract

Recently, a new class of frequency selective surfaces, named as 3D frequency selective structures (FSSs), are reported in order to achieve high performance, such as sharp roll-off and wide out-of-band rejection. In these 3D FSS designs, multiple resonators are constructed, providing a number of transmission zeros/poles at finite frequencies. High performance can then be obtained by controlling locations of these transmission zeros/poles. However, the major disadvantage of these 3D FSSs is their complicated topologies. Most of them require extra assembly process after fabrication, which will increase undesirable errors and uncertainties.

In this talk, a number of 3D FSSs implemented by using multilayered PCB technology are presented. These structures are full printed circuits, which can be fabricated without assembly, thus leading to higher fabrication accuracy and suitable for mass production. It is therefore feasible for this type of FSS to be applied at high frequency applications, such as millimeter-wave systems.

Keywords – 3D frequency selective structures, printed circuit board, spatial filters.

Outline

- Background
  - Brief Introduction to Frequency Selective Surfaces
  - Typical Frequency Selective Surfaces and Their Shortcomings
- 3D Frequency Selective Structures (FSSs)
  - Concept
  - Existing 3D Designs
  - Our Previous Work
- 3D FSSs Using Multilayered PCBs
  - Double-Layer Bandstop Design
  - Miniaturized-Element Design
  - Dual-Polarized Design
- Future Work & Conclusions

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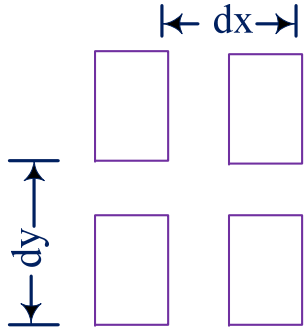
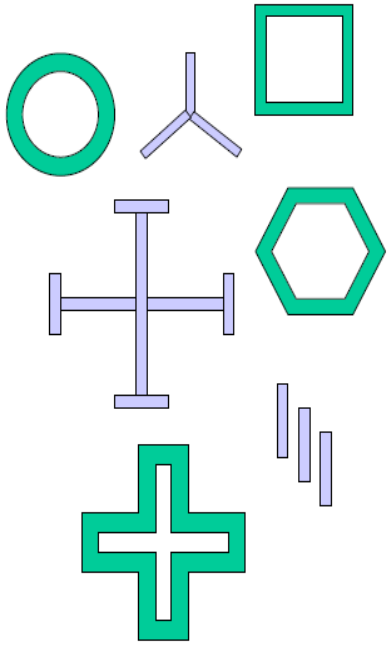
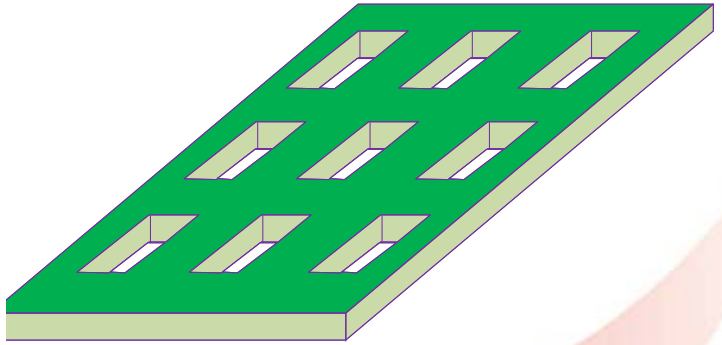
What is Frequency Selective Surface?

- Definition: a surface construction designed as a "filter" for plane waves
  - Frequency/angular response
  - Bandpass and bandstop performances
  - Typically a two-dimensional periodic surface
- Design Parameters
  - Element spacing
  - Element shape
  - Element dimensions
- Applications
  - Radome
  - Sub-reflector
  - Lens







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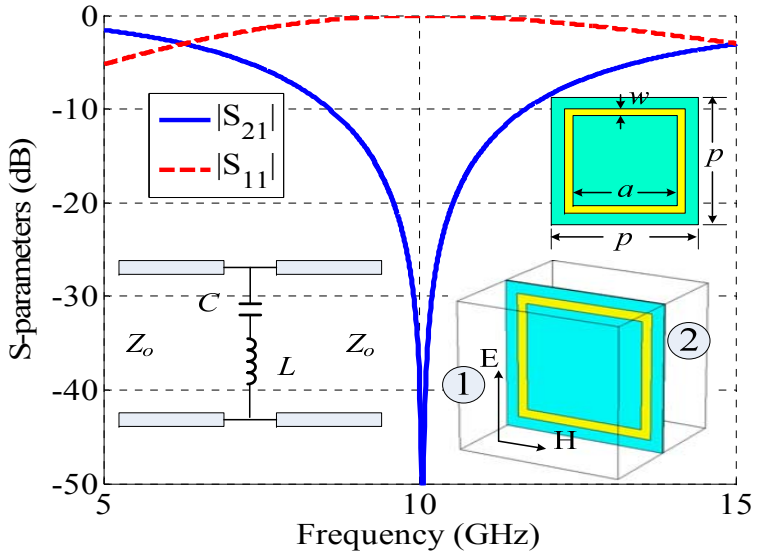
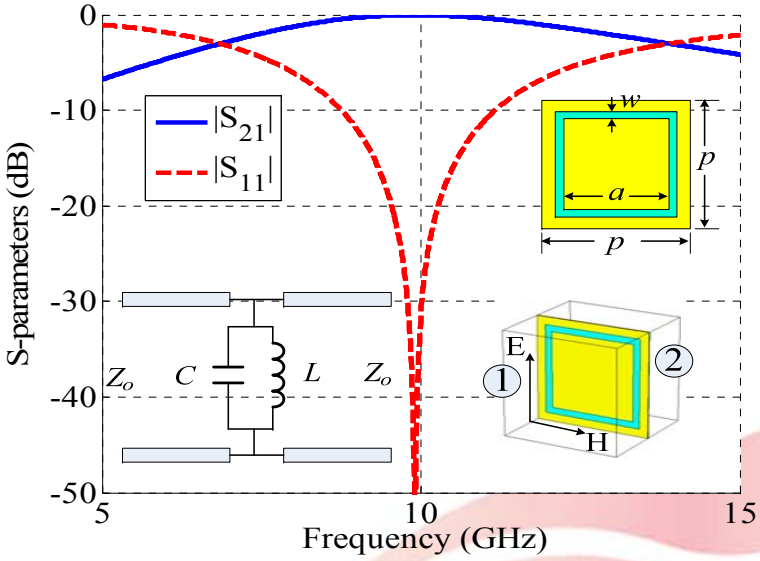
Two Typical Frequency Selective Surfaces

- Single-Layer Surfaces
  - Strip resonators



  - Slot resonators



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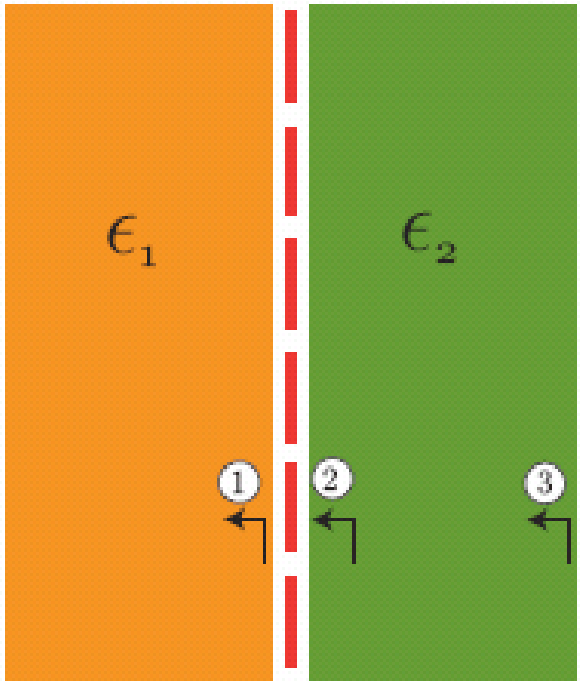
Disadvantages of Traditional Surfaces

- Limited bandwidth: based on one resonance
- Large cell size: typically half a wavelength so that it can resonate. This large cell size results in poor angular response. Munk [1] used two slabs to alleviate the angular sensitivity. Others used miniaturized elements [2].
- Poor filtering response: maximally flat or Butterworth-type filtering response can be achieved.



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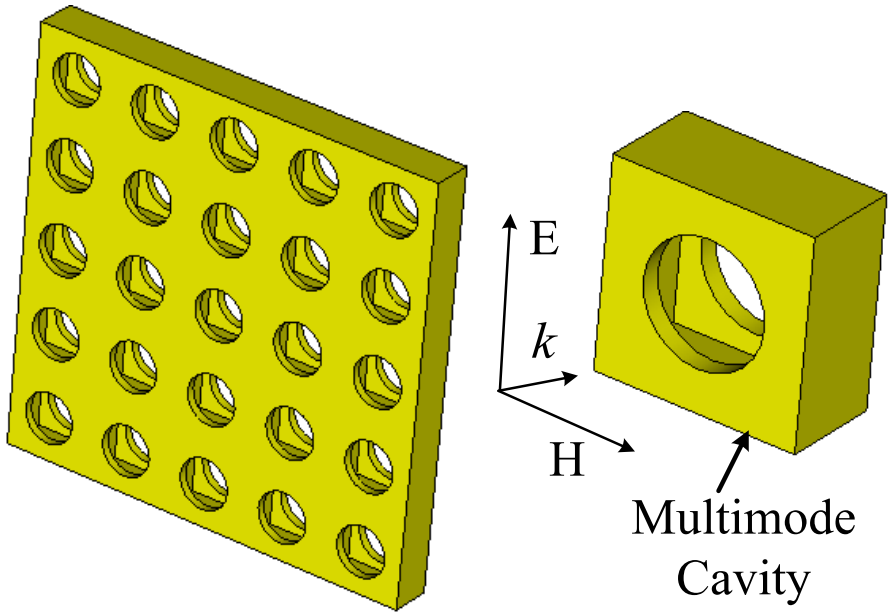
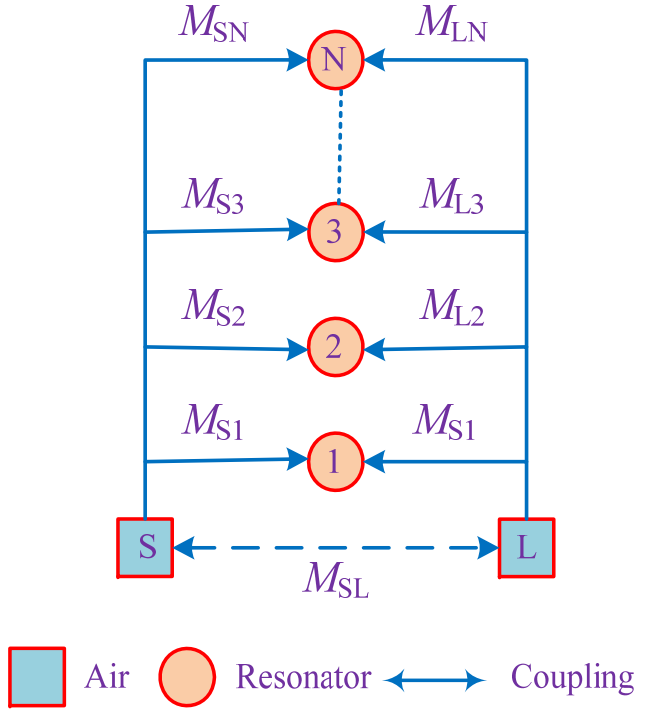
3D Frequency Selective Structures (FSSs)

Generalized Topology [3]



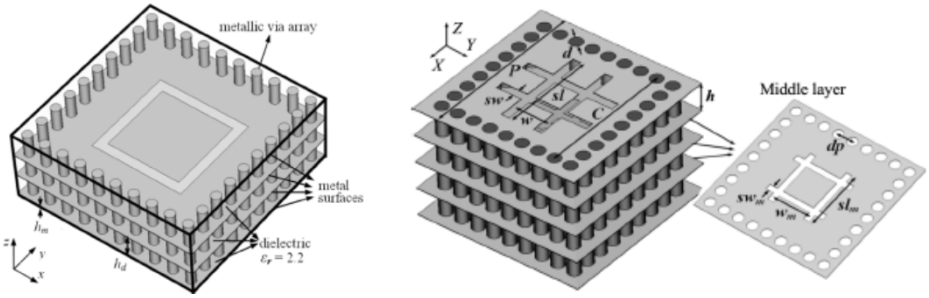
Generalized Circuit Model

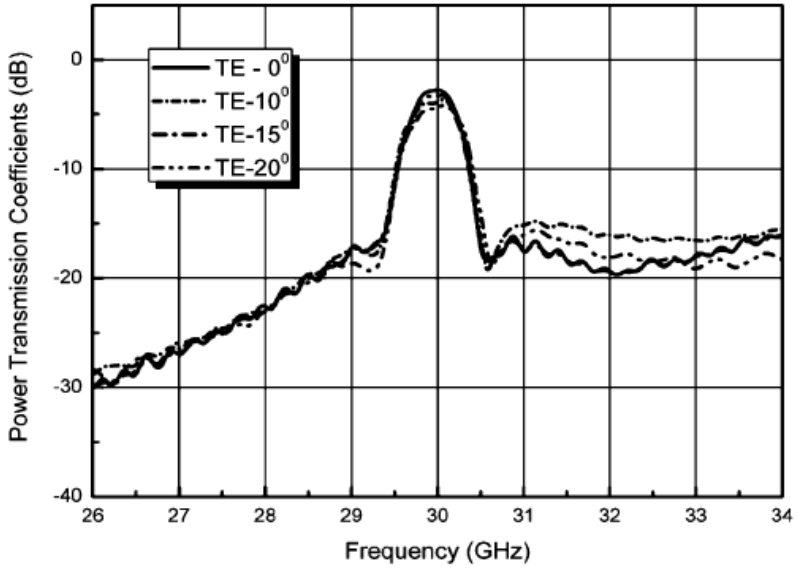


- It is possible to include multiple mode resonances.
- N different paths can generate N reflection zeros.
- Increased coupling to multiple modes results in high performance.

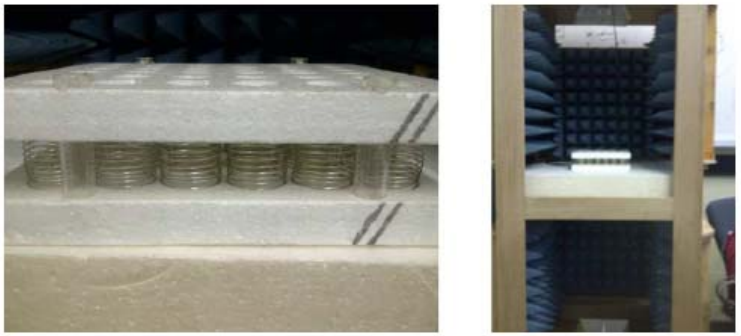
Existing 3D FSS Designs (1)

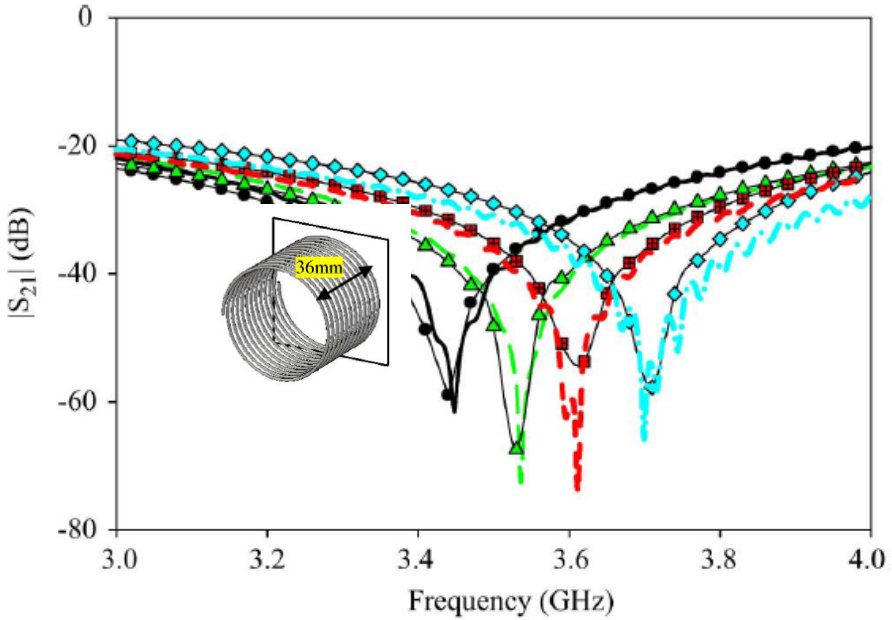
- SIW Structure [4, 5]:





- Cylindrical Ring Structure [6]:





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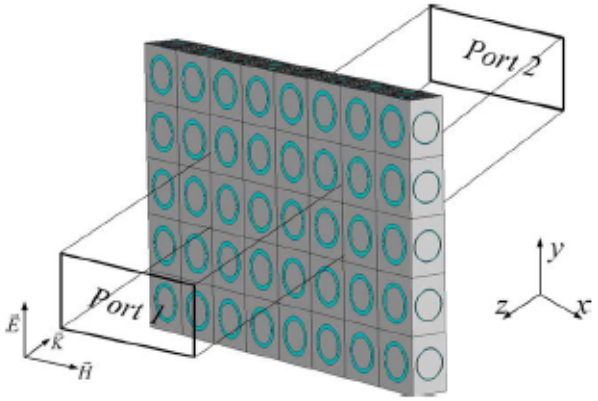
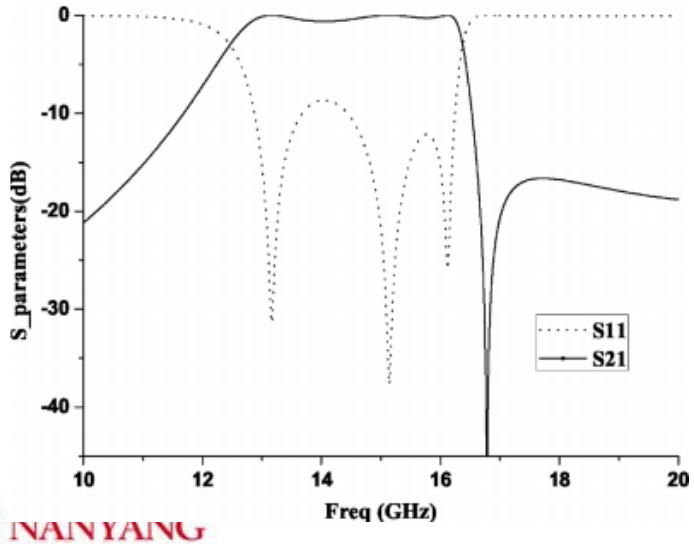
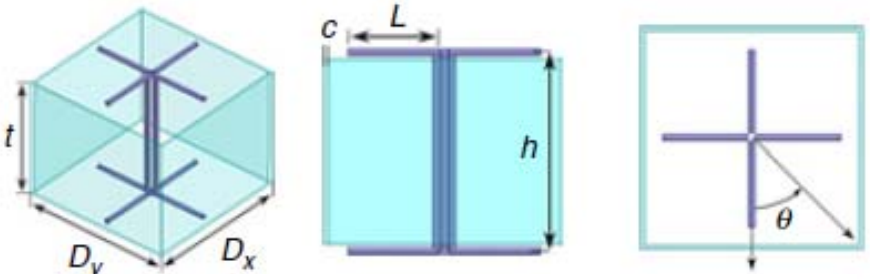
Existing 3D FSS Designs (2)

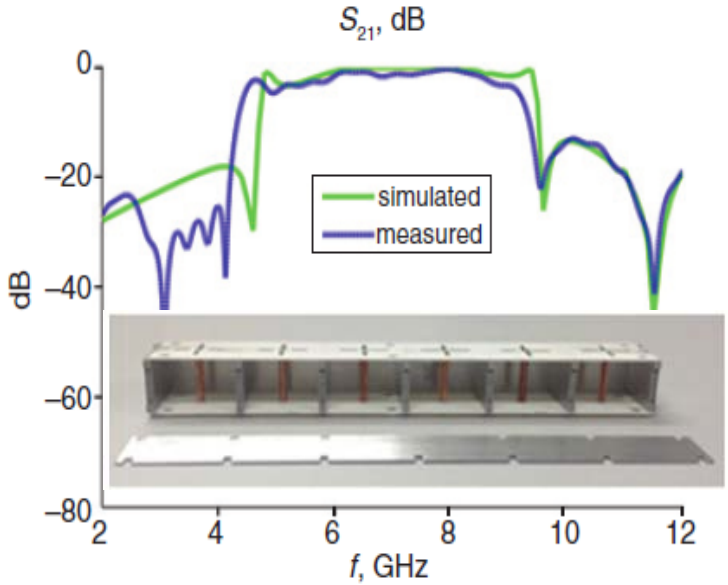
- Apertured Cavity Structure [7]:





- Crossed Dipole + Waveguide Structure [8]:





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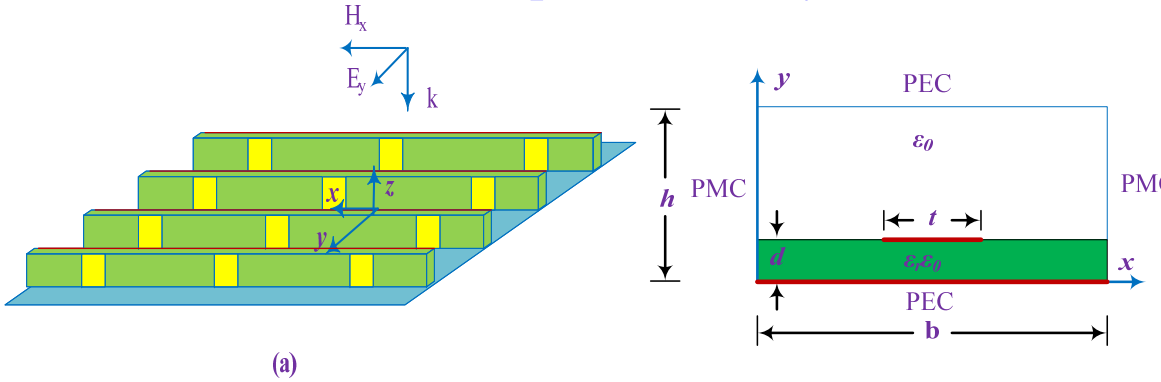
Microstrip-Line Based 3D FSS

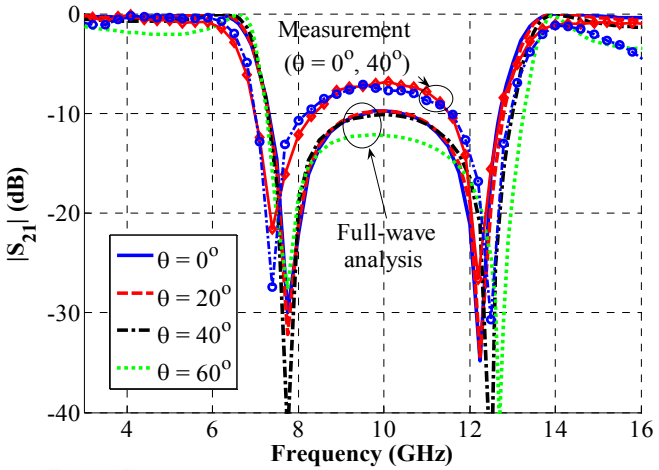
Description of the Structure

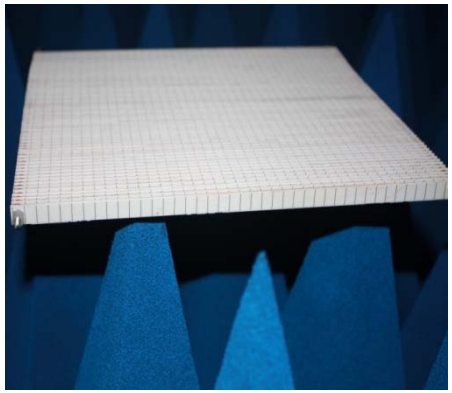
– Two-dimensional periodic array of stacked microstrip lines



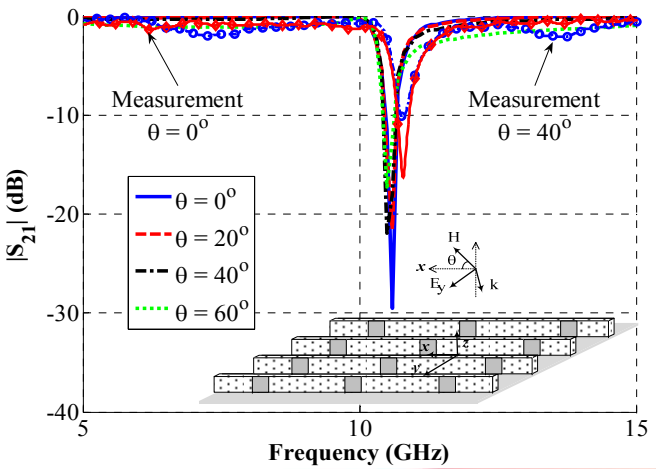
- Dielectric constant.
- Strip width to horizontal period ratio *t*/*b*.
- Substrate height to vertical period ratio *d*/*h*.

- Wide-Band Design [9]





- Narrow-Band Design [9]



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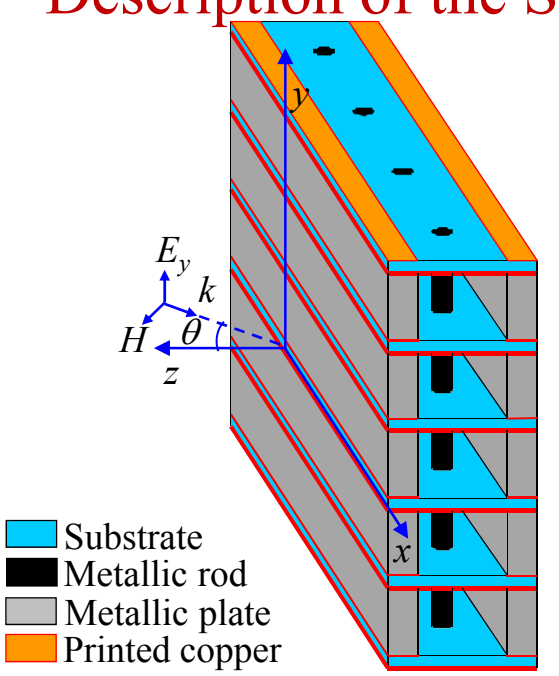
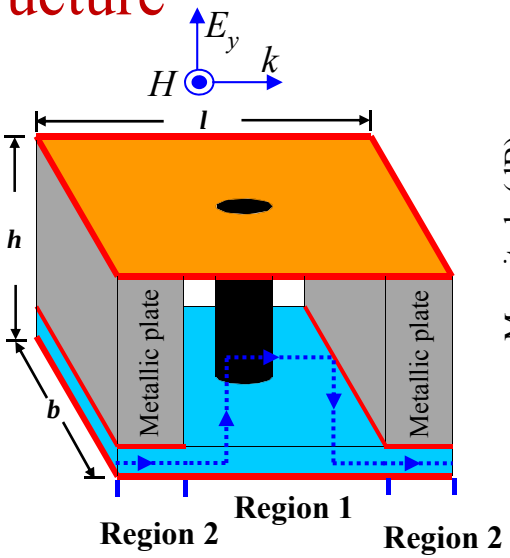
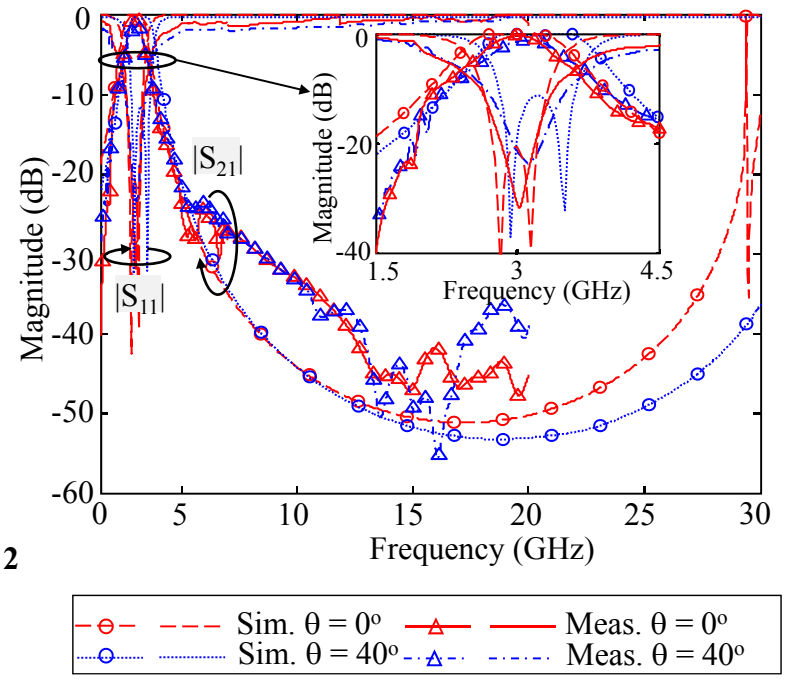
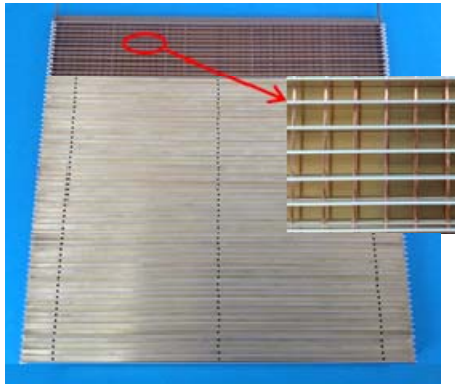
Miniaturized-Element Bandpass FSS

Description of the Structure









Advantages [10]:

- The unit cell size and thickness of the single-polarized bandpass FSS is $0.06\lambda_0 \times 0.045\lambda_0 \times 0.096\lambda_0$ (λ_0 is the free-space wavelength at the center frequency).
- The FSS exhibits an excellent upper stopband suppression of $2f_0$ to $6f_0$ harmonics.

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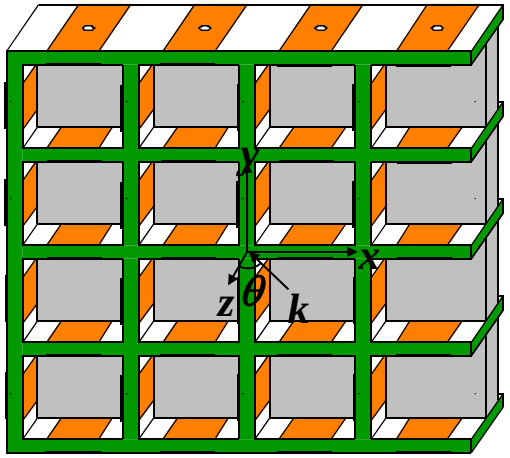
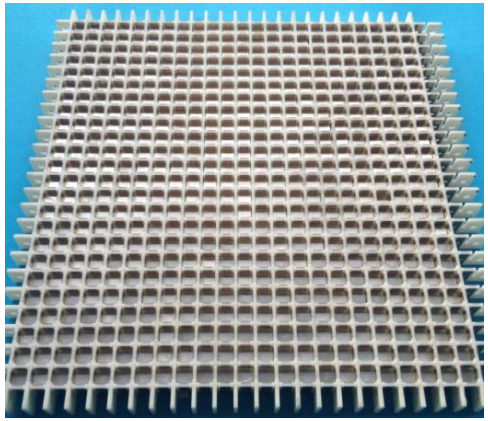
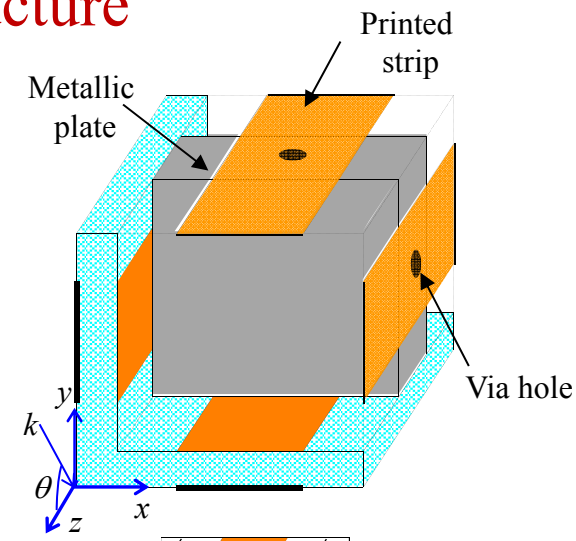
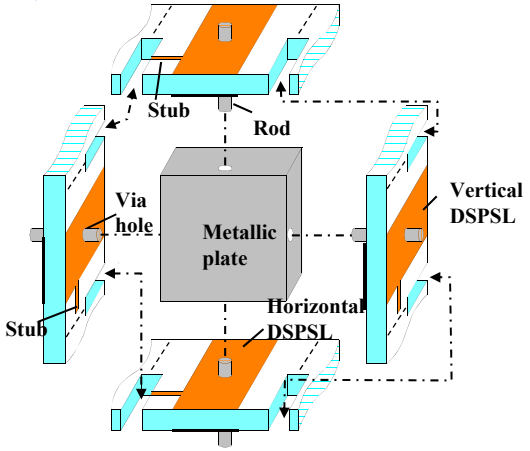
Dual-Polarized Bandpass FSS

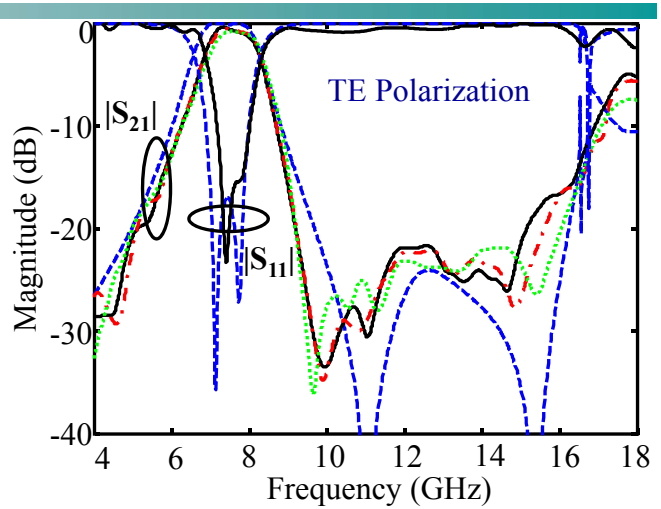
Description of the Structure

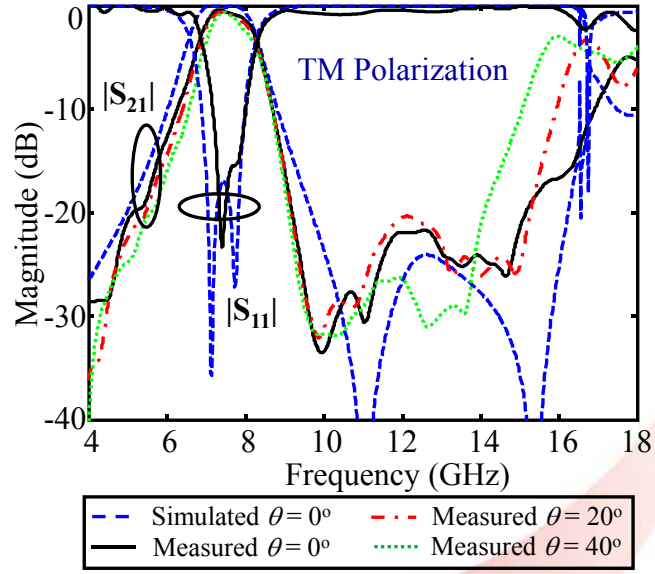












Advantages [11]:

- The designed FSS has a relative 3dB passband bandwidth of 18.4% and a bandwidth of about 78.4% for the out-of-band rejection better than 20dB.
- Dual-polarization is realized.

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Problems & Solution

Problems:

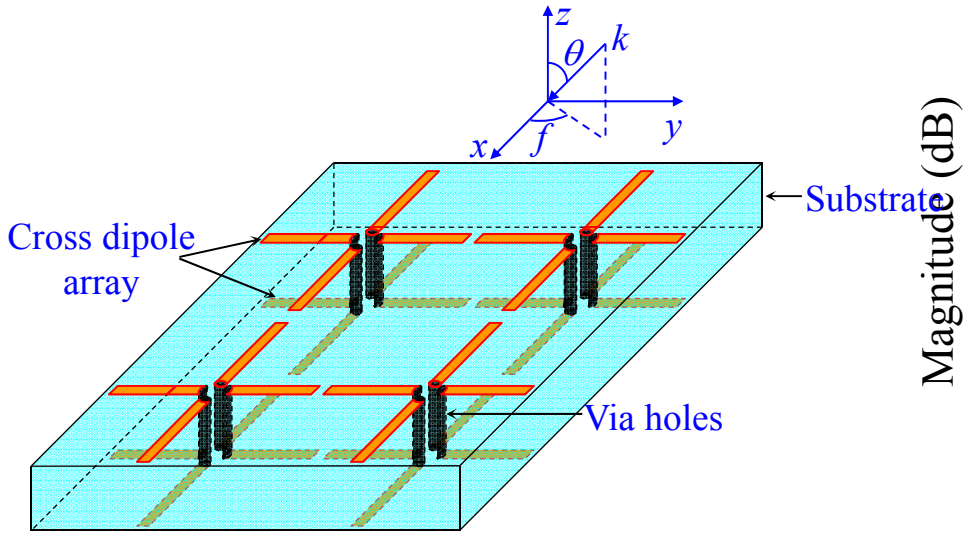
- Not all printed structures
- Assembly procedures are needed
- Large thickness

Solution: Multilayered printed circuits

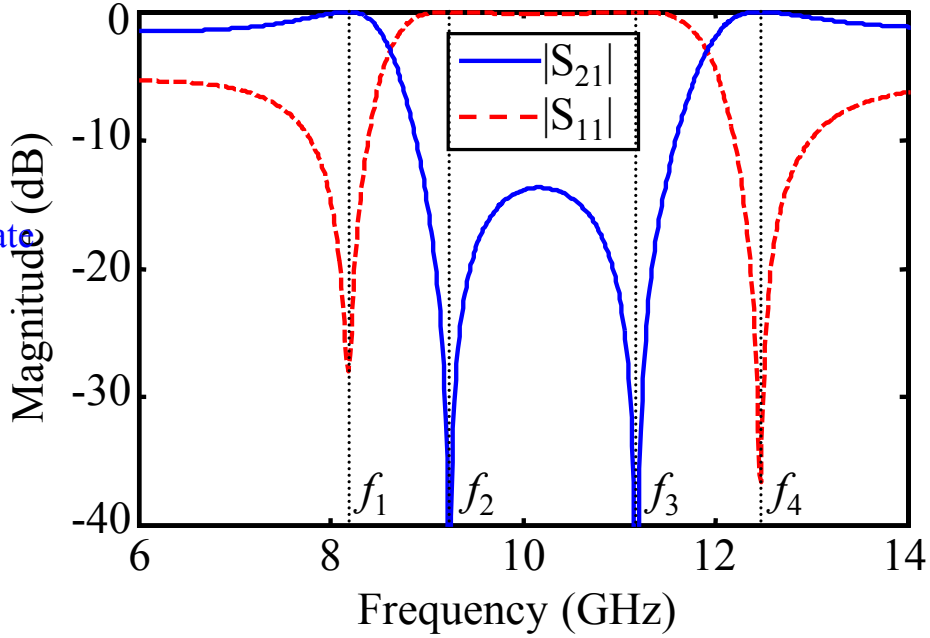
- Double-layer bandstop design
- Miniaturized-element design
- Dual-polarized design

Double-Layer Bandstop Design

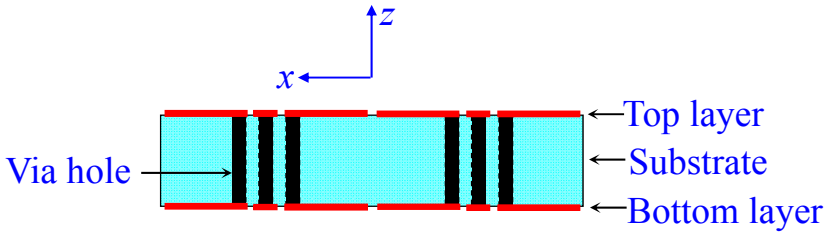
Description of the Structure



Simulated Result:



Side View



Advantages:

- Wideband bandstop filtering response with sharp roll-off.
- Full printed circuits.

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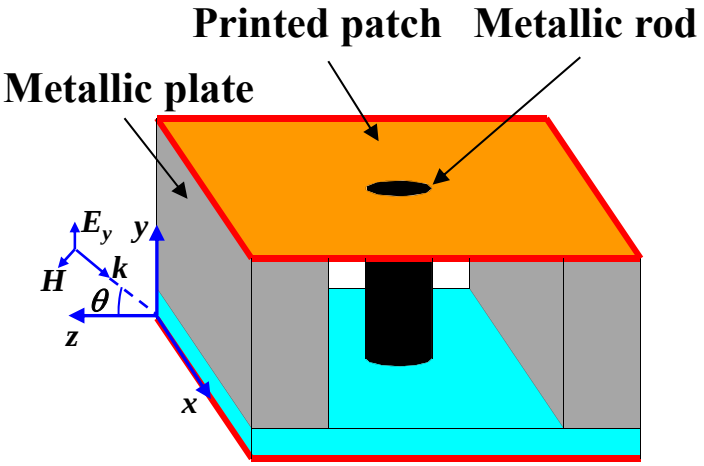
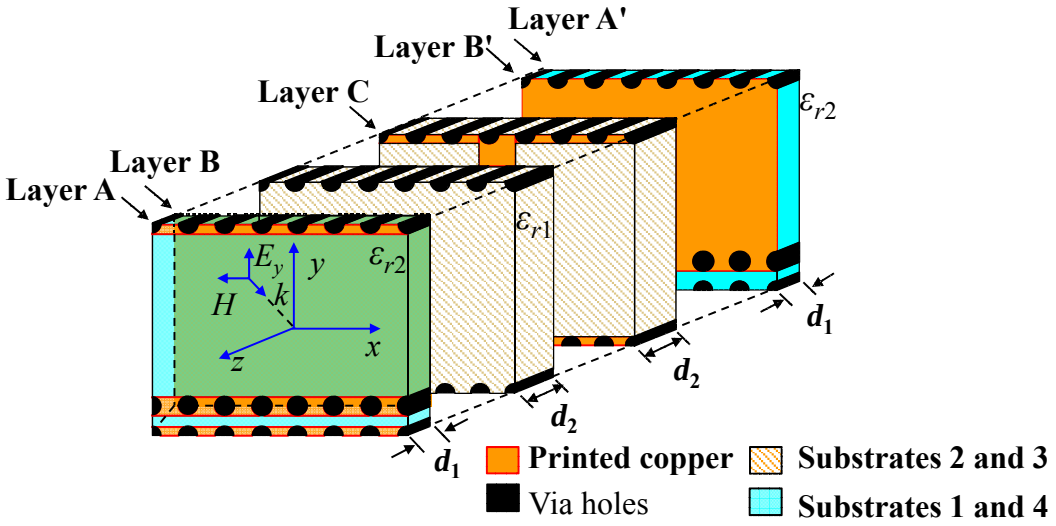
Miniaturized-Element Design

Original Structure (A Unit Cell)



*B. Li and Z. Shen, *IEEE Antennas Wireless Propag. Lett*. vol. 13, pp. 145-148, 2014.

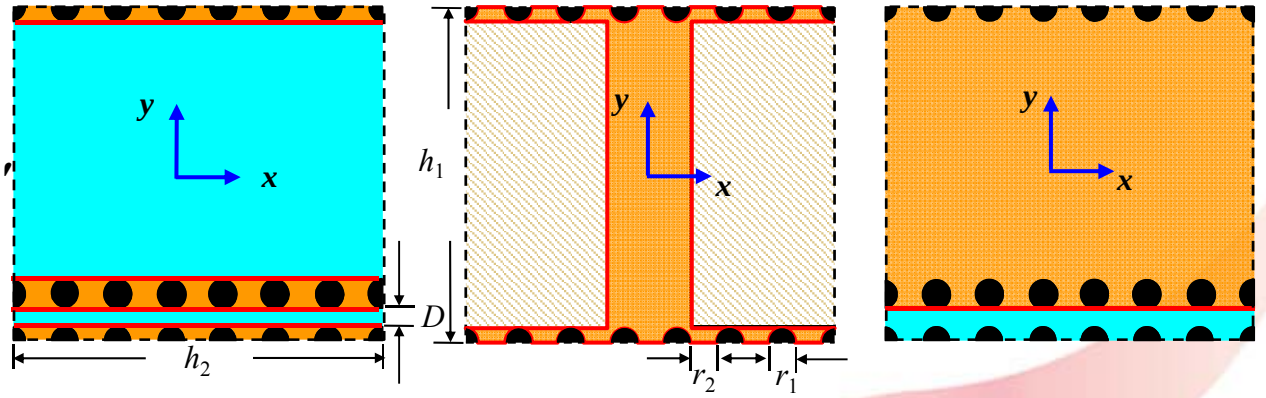
Multilayer Structure (A Unit Cell)



Printed patch ➡ Via holes

Metallic plate ➡ Layer B and B'

Metallic rod ➡ Layer C



(a) Layer A and A' (b) Layer C (c) Layer B and B'

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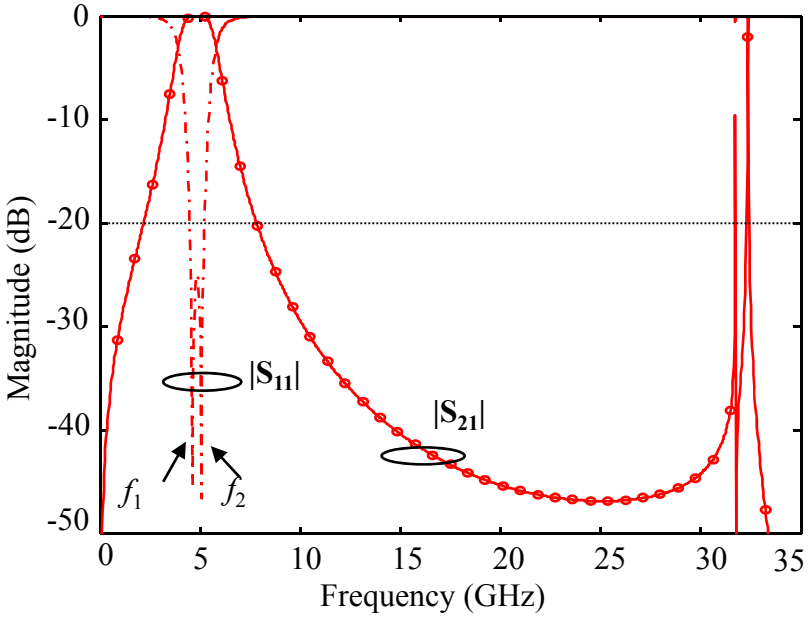
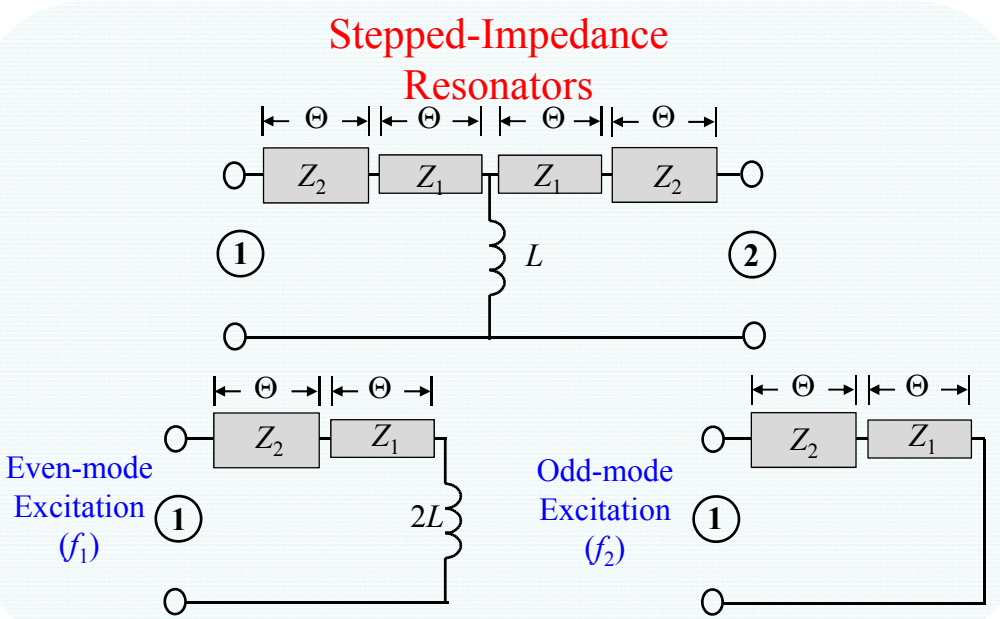
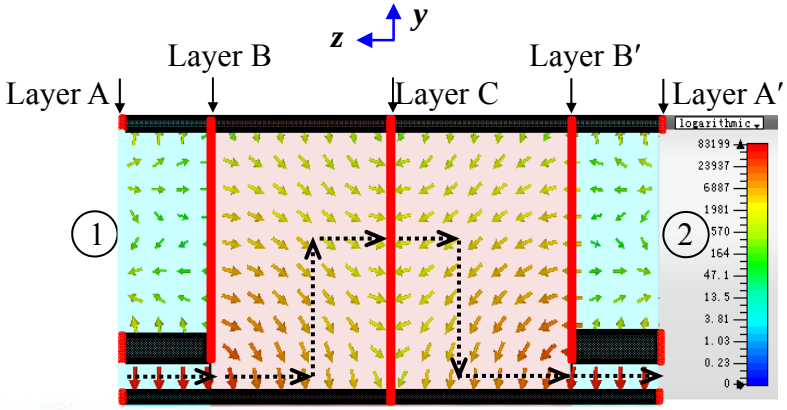
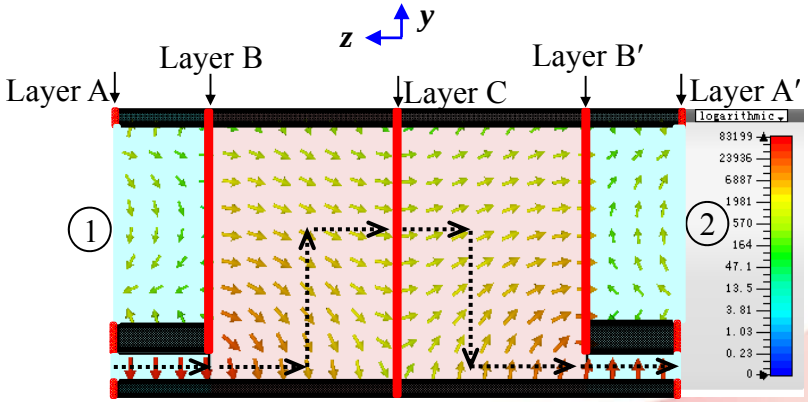
Operating Principle









E-field distributions at f_1 and f_2

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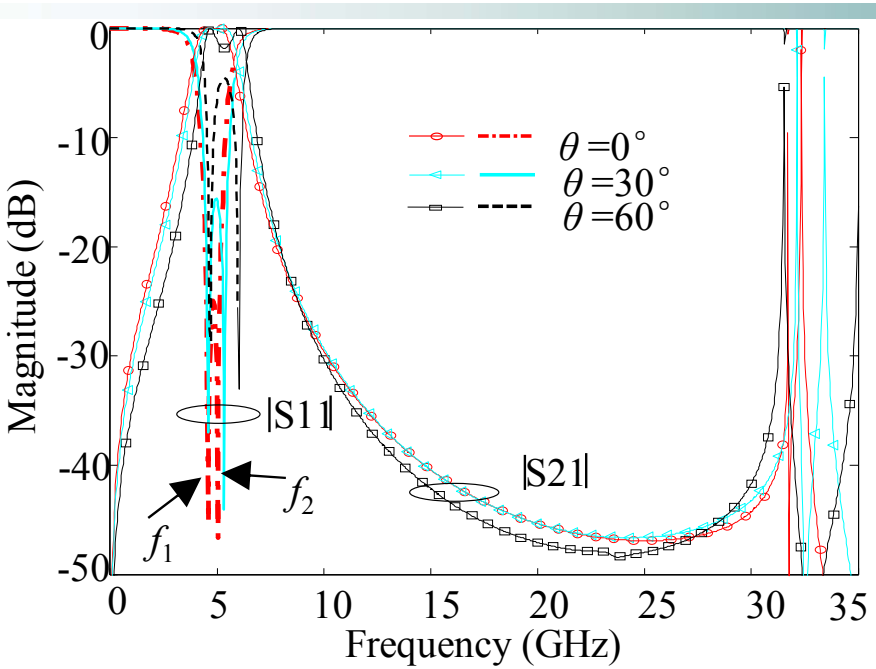
Simulated Results



ε_{r1} =2.2, ε_{r2} = 3.55, d_1 = 1.016mm, d_2 = 2.078mm, h_1 = 3mm, h_2 = 4.2mm, r_1 = 0.3mm, r_2 = 0.3mm, D = 0.3mm, w = 0.85mm

Advantages:

- The unit cell size and thickness of the bandpass FSS is $0.07\lambda_0 \times 0.05\lambda_0 \times 0.1\lambda_0$ (λ_0 is the free-space wavelength at the center frequency).
- The FSS exhibits an upper stopband suppression of $2f_0$ to $6f_0$ harmonics.
- Full printed circuits.

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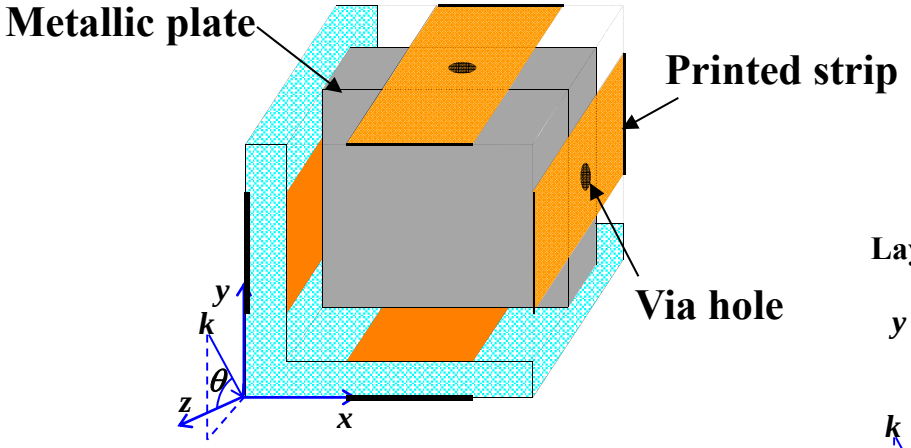
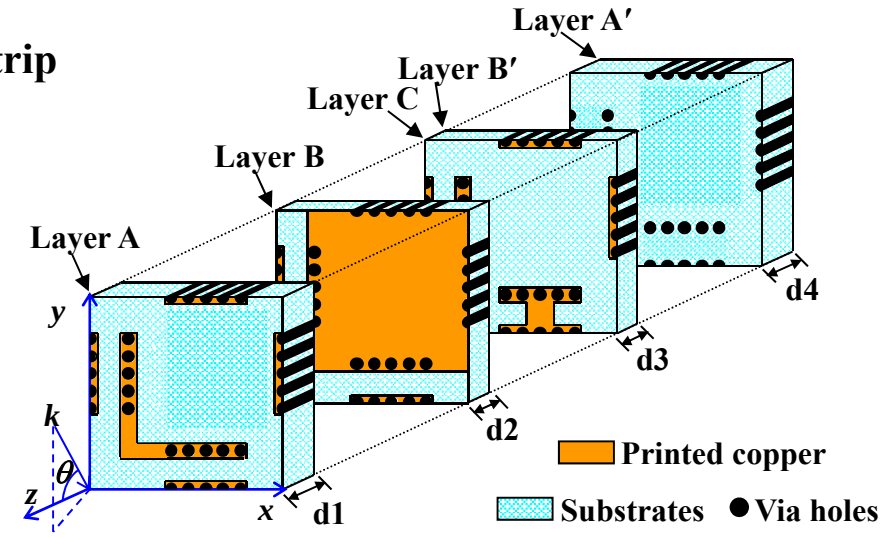
Dual-Polarized Design

Original Structure (A Unit Cell)



*B. Li and Z. Shen, *IEEE Trans. Antennas Propag.*, vol. 62, no. 1, pp. 130-137, 2014.

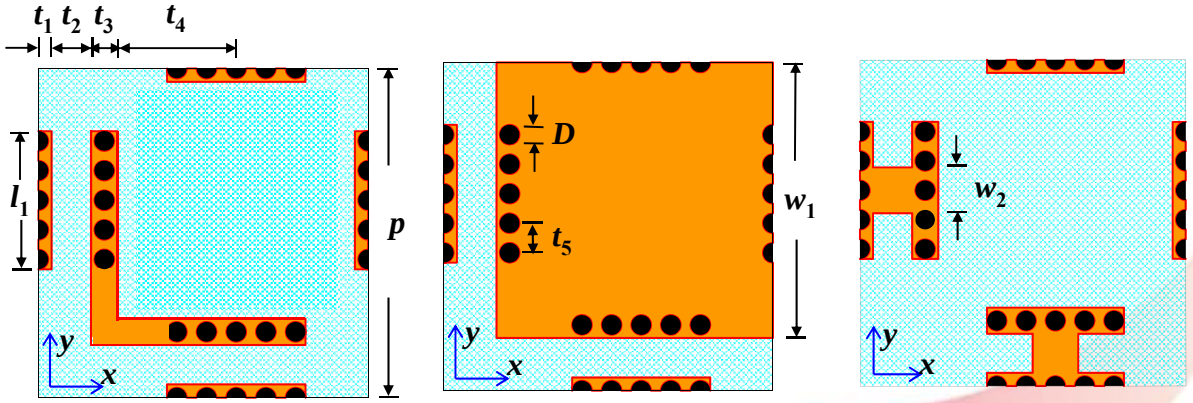
Multilayer Structure (A Unit Cell)



Printed strip ➡ Via holes

Metallic plate ➡ Layer B and B′

Via holes ➡ Layer C



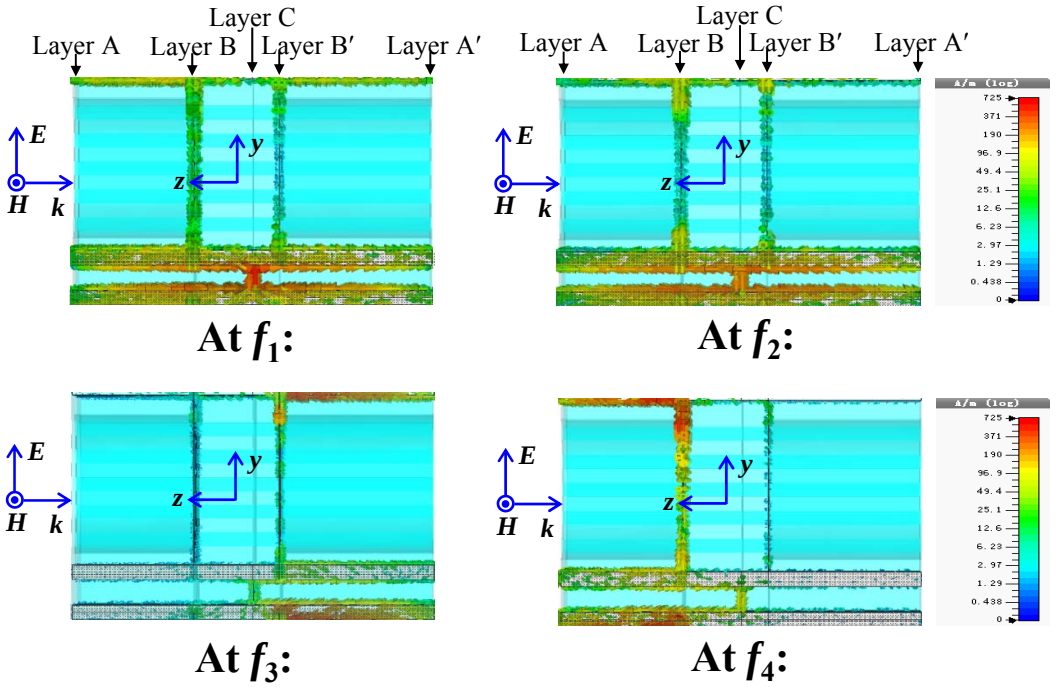
(a) Layer A and A'

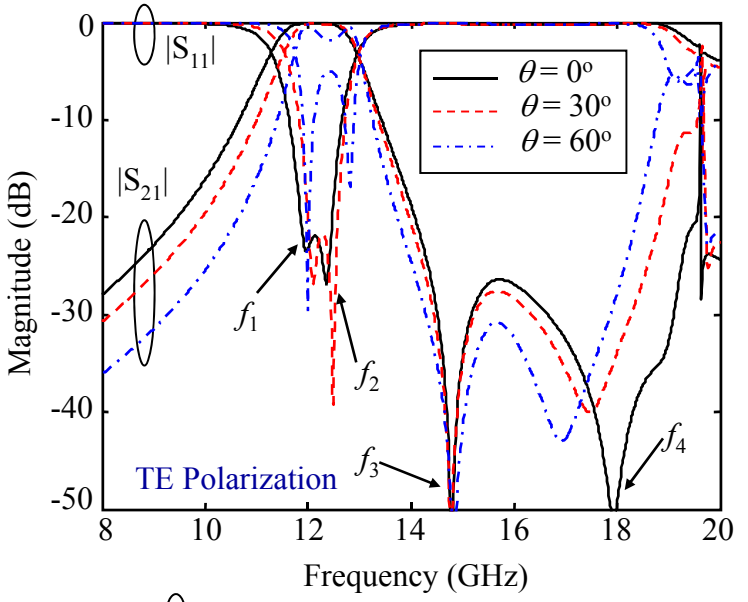
(b) Layer B and B'

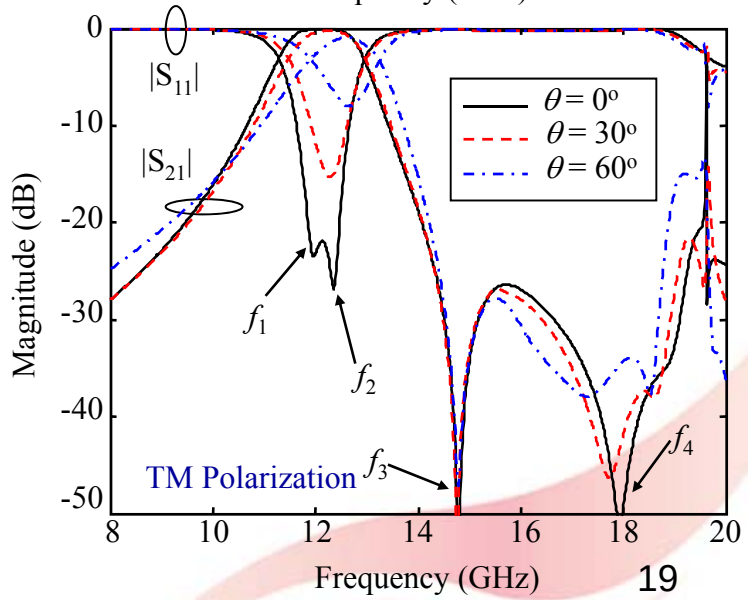
(c)Layer C

Current Distributions

Current Distributions:







ε_r = 3.55, d_1 = 1.93mm, d_2 = 0.813mm, d_3 = 0.406mm, d_4 = 2.337mm, p = 5mm, t_1 = 0.25mm, t_2 = 0.35mm, t_3 = 0.5mm, t_4 = 1.83mm, t_5 = 0.6mm, w_1 = 4.3mm, w_2 = 1.7mm, l_1 = 2.93mm, D = 0.3mm.

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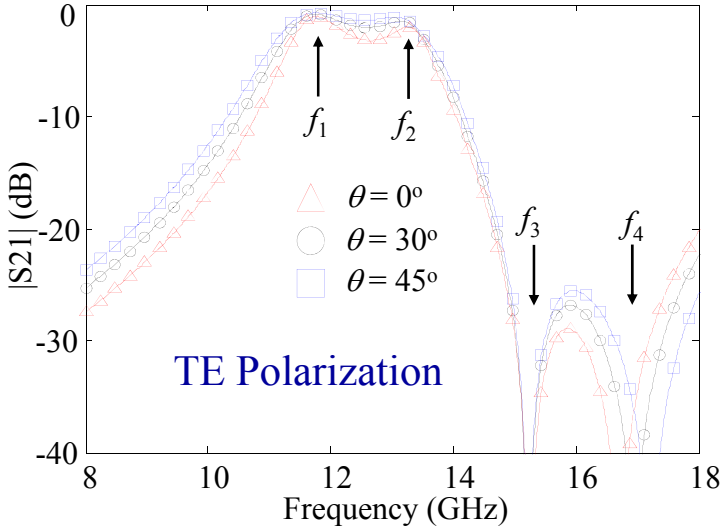
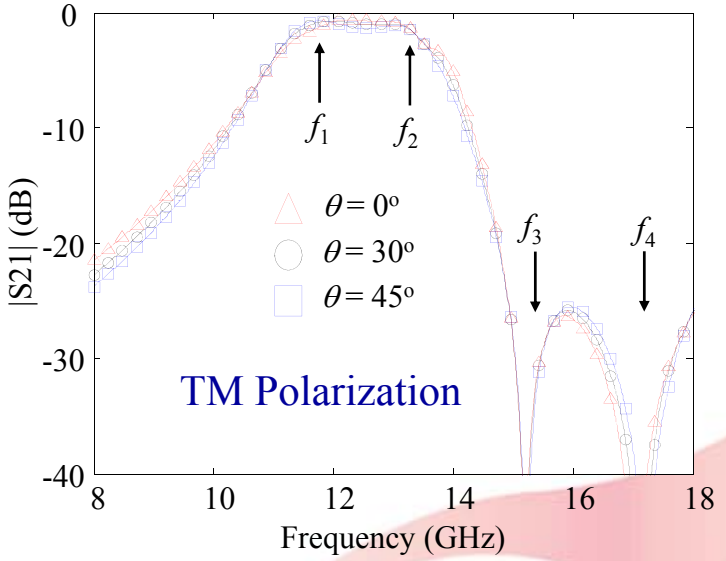
Measurement

Photo:





Advantages:

- Dual-polarization.
- Full printed circuits.

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Future Work

- Design of other multilayered 3D FSSs (dual-band or multi-band response, dual-polarized bandpass and bandstop structures).
- Thickness reduction by using Low Temperature Co-fired Ceramic (LTCC).

Conclusions

- A number of 3D bandpass FSSs based on multilayered PCB technology have been presented.
- Compared with the previous microstrip-line based 3D FSSs, this type of FSS can be fabricated without assembly, thus leading to higher fabrication accuracy.
- It is also easier for this type of FSS to be scaled to high frequency applications, such as millimeter-wave systems.

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Thank you very much!